

# Five important things to consider when doing foliar spraying

Foliar spraying is a true and tested way to increase yields and prevent issues in plant culture. Both soil and hydroponic growers have used foliar fertilizer applications to increase yields and prevent problems due to nutrient deficiencies during the past 50 years. However there is a lot of mystery and confusion surrounding foliar fertilizer applications, reason why this technique is often applied incorrectly or sub-optimally. Today I want to talk about 5 key pieces of information to consider when doing foliar fertilization so that you can be more successful when applying it to improve your crop results and reduce deficiency problems. If you want to learn more about these factors I suggest you read the following reviews on foliar feeding ([here](#), [here](#) and [here](#)). Second table in this post was taken from [this study](#) on wheat.



**Foliar fertilization is not root fertilization.** A usual problem when doing foliar fertilization is to think that the same products can be used for leaves and roots. When you want to increase your crop yields using foliar fertilization you should definitely not use the same products and concentrations you use for soil. There are for example some chemical substances that you would never want to apply to the roots that have actually shown to give better outcomes in leaves. A good example is calcium chloride which is a huge mistake in root fertilizers but a great choice when doing foliar fertilization.

**Foliar fertilizers should generally be much more concentrated.** When people apply foliar fertilization they usually apply much

lower concentrations because they are afraid of burning leaves. Although this can certainly happen if the foliar fertilizer is badly designed research has shown that the best results are obtained with much higher concentrations than what you generally use for the roots. For example when you apply an iron foliar fertilization regime you generally use a concentration of 500-1200 ppm of Fe while in root applications you only very rarely go beyond 4-5 (most commonly 1-3 ppm). Usually concentrations in foliar fertilizers will be much higher and if the fertilizer is correctly designed this will give much better results. The graph below (taken from the first review linked above), shows some of the most commonly used fertilizer concentrations.

Table 3  
Amount of fertilizers and water volume used in foliar spray of macro and micronutrients

Nutrient	Formulation or salt	Kg per 500 liter of water
N	CO (NH <sub>2</sub> ) <sub>2</sub>	3-5
N	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> ; NH <sub>4</sub> NO <sub>3</sub> ; (NH <sub>4</sub> ) <sub>2</sub> HPO <sub>4</sub> ; NH <sub>4</sub> Cl; NH <sub>4</sub> H <sub>2</sub> PO <sub>4</sub>	2-3
P	H <sub>3</sub> PO <sub>4</sub> ; others see N above	2-3
K	KCl; KNO <sub>3</sub> ; K <sub>2</sub> SO <sub>4</sub>	1.5-2.5
Ca	CaCl <sub>2</sub> ; Ca(NO <sub>3</sub> ) <sub>2</sub>	1.5-2.5
Mg	MgSO <sub>4</sub> ; Mg(NO <sub>3</sub> ) <sub>2</sub>	3-10
Fe	FeSO <sub>4</sub>	3-6
Mn	MnSO <sub>4</sub>	1-2
Zn	ZnSO <sub>4</sub>	1.5-2.5
Cu	CuSO <sub>4</sub>	0.5-1
B	Sodium borate	0.25-0.5
Mo	Sodium molybdate	0.1-0.15

Source: Adapted from Fageria et al. (1997); Fageria and Barbosa Filho (2006).

**Surfactants are very important (don't use dish washing soap!).** Leaf coverage is very important in foliar applications because you want the fertilizer to be evenly spread across the entire leaf not "clumped" into drops due to surface tension. Many people have trouble with nutrient burn due to bad fertilizer design that causes inadequate leaf coverage. However all surfactants are not created equal and ionic fertilizers are very undesirable for this task due to their interaction with leaf tissue and fertilizers. Due to this reason you should NOT use something like dish washer liquid soap but a proper non-ionic surfactant like a polysorbate. The surfactant will be a very important part of your foliar fertilizer formulation.

**Timing is also critical.** The time when you do your foliar sprays applications is also very important for optimal results. In general you want the leaf stomata to be open and the vapor pressure deficit to be lower so the best time to do foliar spraying is usually during the afternoon after temperatures have dropped significantly. For most time zones this usually means sometime after 3PM. Doing foliar applications sooner can lead to much larger stress due to a higher vapor pressure deficit – risking burns as well – while doing it later leads to less efficient absorption due to the stomata being closed. If applying the spray at this time is not possible then early morning often works as well. Make sure you measure your daily temperature/humidity fluctuations to ensure you don't do foliar sprays at a high VPD.



**Couple adequate additives for yield increases.** Research has shown that while nutrient foliar spraying can enhance yields significantly under sub-optimal root feeding conditions if the root concentrations are already optimal – as in a well managed hydroponic crop – it is hard for simple nutrient foliar spraying to provide a lot of benefit. However there are several biostimulants that are poorly absorbed through the root zone that can give you much better results when used as foliar sprays. Additives like salicylic acid and triacontanol can make sure that your nutrient foliar spray gives you maximum additional benefits.

As you can see there is a lot to the design of an adequate foliar spray. You must consider that the substances you use need to be fit to the purpose – not necessarily the same as for root applications! – and that your concentrations, surfactants, additives and application times are adequate. Now that you are aware of these factors you should take them into account when designing your next round of foliar spraying for your crops.

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# Creating a robust pH/EC monitor for hydroponics using Atlas probes and an Arduino

A few months ago I talked about how you could build a simple sensor station for your hydroponic projects using an arduino (see [here](#)). However this small project used the relatively cheap – but I have found not very robust – pH/EC probes and boards from gravity which makes it a poorer choice for a more professional project aiming to constantly monitor the pH/EC of a production hydroponic setup. Today I am going to tell you how you can build a dedicated pH/EC monitor using the robust pH probes from Atlas, which also have several important advantages we will be discussing within this post. *I would also like to point out that Atlas is not paying me anything to write this post, I write just because of my experience using their probes.*

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Whitebox Labs

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The pH/EC probes from gravity have several problems when looking for a robust sensing setup. The first issue they have is that the probes are not rated for constant immersion, so they are damaged if you place them within solution the whole time which is probably what you want to do within a production hydroponic setup. The second issue is that the boards require cable connections to the Arduino which introduces a significant amount of noise that can cause problems with measurements. Due to poor isolation there can also be issues with the gravity boards when measuring EC/pH at the same time. To overcome these issues we can use probes and boards from atlas which have the advantage of having no cable connections to the Arduino – connections are through pins directly – plus the probes are rated for constant immersion and are much more robust. These are the things we would need to build this project:

- [Arduino UN0 R3](#) – 23.90 USD
- [LCD 12864 screen shield](#) – 24.05 USD
- [Mini tentacle shield](#) – 85.00 USD
- [pH kit from Atlas](#) – 149.15 USD



## CALIBRATION

```
#define EC_PARAM_A 0.00754256
```

```
//pH values // CHANGE THESE PARAMETERS FOR PH PROBE  
CALIBRATION
```

```
#define PH_PARAM_A 1.0
```

```
#define PH_PARAM_B 0.0
```

```
#define XCOL_SET 55
```

```
#define XCOL_SET2 65
```

```
#define XCOL_SET_UNITS 85
```

```
//-----
```

```
U8GLIB_NHD_C12864 u8g(13, 11, 10, 9, 8);
```

```
float pH, EC;
```

```
//-----
```

```
void draw() {
```

```
    u8g.setFont(u8g_font_04b_03);
```

```
    u8g.drawStr(0,11,"pH:");
```

```
    u8g.setPrintPos(XCOL_SET,11);
```

```
    u8g.print(pH);
```

```
    u8g.drawStr(0,21,"EC:");
```

```
    u8g.setPrintPos(XCOL_SET,21);
```

```
    u8g.print(EC);
```

```
    u8g.drawStr( XCOL_SET_UNITS,21,"mS/cm" );
```

```
}
```

```
void read_tentacle_shield(){
```

```
    for (int channel = 0; channel < TOTAL_CIRCUITS; channel++) {
```

```
        Wire.beginTransaction(channel_ids[channel]);
```

```
        Wire.write('r');
```

```
        Wire.endTransmission();
```

```
        delay(1000);
```

```
        sensor_bytes_received = 0;
```

```
        memset(sensordata, 0, sizeof(sensordata));
```

```

Wire.requestFrom(channel_ids[channel], 48, 1);
code = Wire.read();

while (Wire.available()) {
  in_char = Wire.read();

  if (in_char == 0) {
    Wire.endTransmission();
    break;
  }
  else {
    sensordata[sensor_bytes_received] = in_char;
    sensor_bytes_received++;
  }
}
if (code == 1){
  if (channel == 0){
    pH = atof(sensordata);
    pH = pH*PH_PARAM_A + PH_PARAM_B;
  }
  if (channel == 1){
    EC = atof(sensordata);
    EC = EC*EC_PARAM_A;
  }
}
}

void setup()
{
  pinMode(13,OUTPUT);
  Serial.begin(9600);
  u8g.setContrast(0);
  u8g.setRot180();
}

void loop()
{
  digitalWrite(13, HIGH);
  delay(800);
}

```



```
digitalWrite(13, LOW);
read_tentacle_shield();

u8g.firstPage();
do {
    draw();
}
while( u8g.nextPage() );
}
```

Once you have changed the EZ0 boards to i2C you can now plug everything into the arduino and upload the code into your arduino. Plug the EZ0 boards into the mini tentacle shield and then plug that shield into the arduino. You'll notice that the EZ0 boards make it impossible to plug the LCD screen directly on top – as the EZ0 circuits make the shield too tall – so you should use stackable headers to extend the connections so that you can plug the LCD screen on top without any problems. Make sure you download and install the [U8glib library](#) in your arduino IDE before uploading the code.

As with the previous code you'll notice there are variables called PH\_PARAM\_A, PH\_PARAM\_B and EC\_PARAM\_A within the beginning of the code that you should change in order to calibrate your probes. Follow the instructions about calibration I gave in the [previous post](#) in order to figure this out. Using the calibration solutions that come with your kits you'll be able to perform this calibration procedure. Whenever you want to calibrate your probes you should reset these variables to their original values, reupload the code and retake measurements.

Following this guide you will have a very robust sensor setup using very high quality probes. These probes are also coupled with a board that has no wire connections with the arduino, offering very high quality readings with very small amounts of noise. Additionally the LCD shield opens up the possibility to add more sensors to your station so that you can monitor, temperature, humidity, and carbon dioxide potentially from a

single place.

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# Comparing the conductivity of two different solutions

Conductivity is perhaps the most misunderstood and erroneously used measurement in hydroponic culture. This has a lot to do with conductivity also being called a “totally dissolved solid” (TDS) measurement and the conductivity scale being expressed in “ppm” units, concentration units which only cause confusion in this area. Today I want to talk about an important consequence of this confusion that happens when you try to compare the conductivity of different nutrient solutions. I’ll talk about a recent case I encountered and how it generated significant problems due to a natural misunderstanding of how conductivity works.

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**“If we learn from our mistakes, shouldn’t I try to make as many mistakes as possible?”**

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A grower wanted to run a side by side trial of two nutrient formulations using identical growing conditions. This grower

then decided that the best way to do this was to ensure that the conductivity and pH of the two solutions were identical after preparing the nutrient solutions, then they would both be equivalent in terms of their strength and differences in results would be entirely due to the differences in ionic ratios between both of them. The media was the same, the environment was the same and plant genetics were the same.

However there was a small problem with this thinking. **The same conductivity across two different solutions is not the same thing.** You might think that using a conductivity of 2.0 mS/cm across two different nutrient solutions might mean that their “strength” is the same, but in reality the strength of a solution – as per what a plant really experiences – is determined by its osmotic pressure and osmotic pressure – although proportional to conductivity within the same solution – cannot be extrapolated when the composition of the solution changes. This confusion is further expanded when people see the conductivity numbers in ppm because the expression in mg/L makes them think there is the same “amount of stuff” in the two solutions. This is not the case.

All the ppm does is tell you that your solution has the same conductivity as a reference with that ppm concentration (commonly NaCl or KCl) but it tells you nothing about how many dissolved solids are really present within your nutrient solution. Given that non-conductive substances also affect the osmotic pressure of a solution it can happen that a nutrient solution with the same conductivity as another one in reality has a lot more dissolved solids, making it far more concentrated in real terms compared to the other one.

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In the above mentioned particular case one solution had a chelating agent that effectively made a significant number of ions neutral in charge (effectively making them non-conductive) reducing the measured conductivity by around 20% at the same osmotic pressure as the other solution. So while the grower was feeding the two solutions at the exact same conductivity, the second solution was around 20% more concentrated in real terms – osmotic pressure terms – compared to the other one. Plants responded very negatively to this – as the conductivity was already quite high – so the grower erroneously assumed that this was due to the ionic ratios instead of it simply being due to an error in judging concentrations. *The second solution was a lot stronger in real terms, although the conductivity was the same.*

When comparing two nutrient solutions you should therefore resort to measurements different than conductivity because the conductivity of two different solutions with different ion compositions cannot be compared, **the same level of conductivity will result in two completely different osmotic pressure values. Their strengths will *not* be the same.** If you want to compare two different solutions at the same real

strength then you need to use an osmometer to determine this point and sadly osmometers are neither cheap nor practical to use.

However another possibility is to simply compare at a constant concentration of a given element. Have a lab analysis of the two fertilizers made – remember you cannot trust labels to give you the real composition values – calculate how much of a given element, for example N, is present at a given application rate and then dial in the other fertilizer to match that N concentration. The osmotic pressures will probably be different but at least under this sort of A/B test you will be comparing apples to apples in the sense that the only variable will be the N:X ionic ratios between the two solutions. Total strengths will differ but this will be due to differences in ionic ratios, which is probably what you want to test.

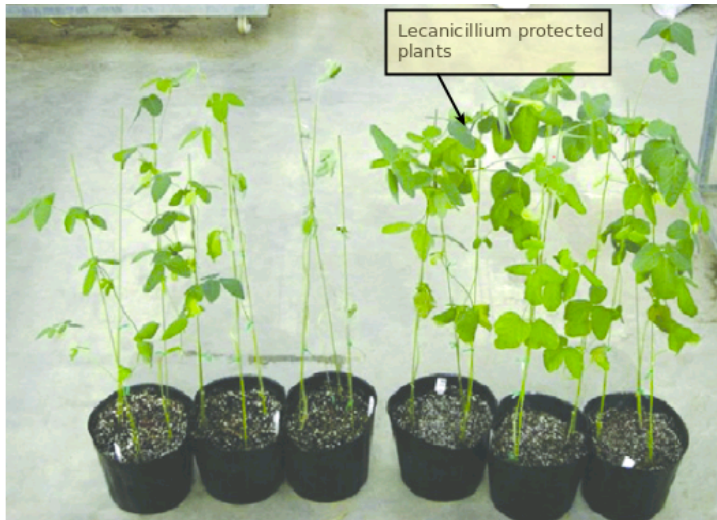
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## **Controlling aphids in a hydroponic crop. Part 1.**

Without a doubt aphids are one of the most common pests affecting crops worldwide. There are both root and leaf aphids, the former which generally live only around plant roots – producing winged offspring only to infest new plants – while the later live generally in plant stems, leaves and – when infestations are bad enough – even within plant flowers and fruits. Today we are going to talk about several alternatives to deal with aphids, from traditional insecticides to more natural alternatives such as biocontrol

options. We are not going to discuss mechanical options here – we'll leave that to part two – as we'll focus only on chemical and biological control within this first part.

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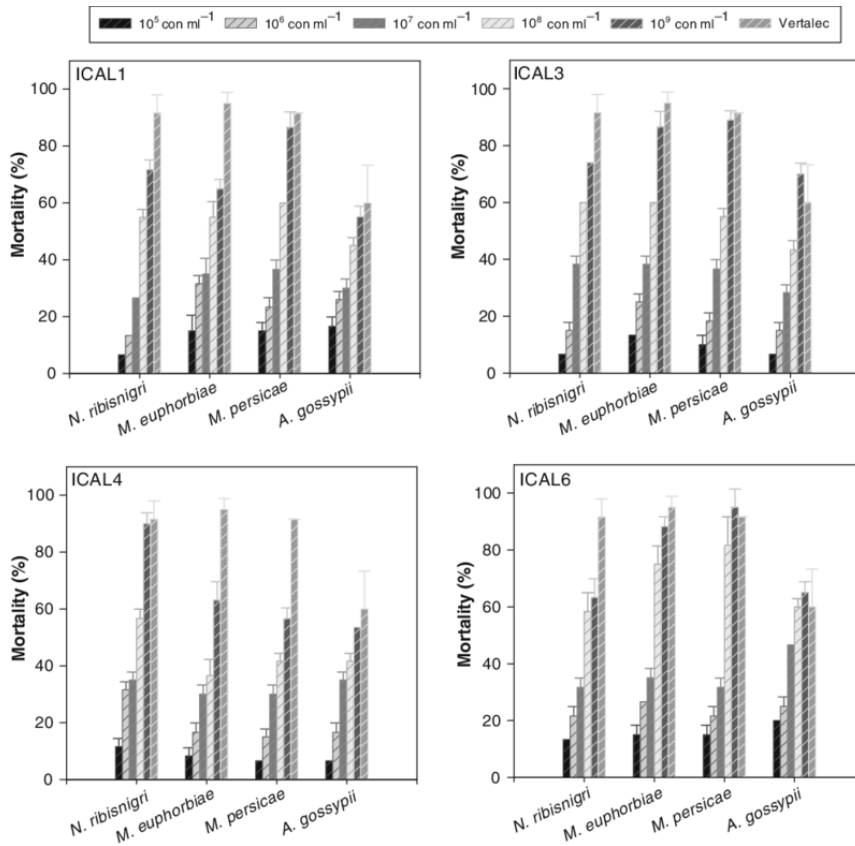
There is one clear winner when controlling aphids. At the present time nothing will beat neonicotinoids in fighting aphids as these insecticides are very effective against a wide range of sucking insects (which are insects that suck material out of plant tissues). Originally made during the mid 1980's and massively popularized during the 1990's (see [here](#)) insecticides like imidacloprid have been huge winners in the fight against aphids. They are applied via soil applications – no need for foliar applications – where they are absorbed by the roots and effectively make plant tissue completely toxic for aphids, affecting their nervous system.

However everything is not rosy with insecticides like imidacloprid. Neonicotinoids affect beneficial insect populations – bees in particular (see [here](#)) – so they are not good for the environment in general. As a secondary problem they also remain within plants for a really long time so they should only be used when plants are a significant time away from harvest (at least 60 days is usually recommended). When

using on edible crops make sure you get a formulation that has been specifically designed for this purpose (like [this one](#)). However some legislations require no imidacloprid to be present in plant tissue meant for human consumption so it is important to check with regulatory guidelines regarding its use. There are several studies showing how imidacloprid can accumulate in fruits and flowers (see [here](#) for an example in maize, [here](#) for an example in tomatoes).

Perhaps we can resort to less damaging alternatives but still control aphids effectively. Predatory insect applications don't work very well (another post about this coming soon!). But one of the best alternatives I have found so far is to use *Lecanicillium Lecanii* – and other *Lecanicillium* species – as a parasitic fungus to attach the aphids. Not only are they effective in attacking aphids but they can also be used as a two-for-one control against powdery mildew and other pathogens as well (see [here](#), [here](#) and [here](#)). I have had a few recent experiences with customers that have had good success using such fungi to control aphids in several crop types, including parsley and tomatoes. I have had great personal success in parsley, basil and mint plants. These two are the products that I have seen used containing this fungi ([here](#) and [here](#)). Image below taken from [this paper](#) and first image in this post taken from [this paper](#).

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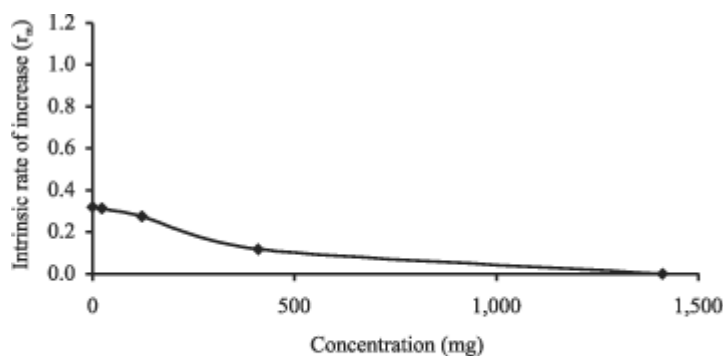


There are also some naturally occurring insecticides that can be used, such as neem oil based products. The problem with these insecticides is that they do work – sort of- depending on the plant and aphid specie you are trying to tackle (see [here](#)). Generally 0.2-0.5% emulsions of the oil are effective against aphid populations with such application generally killing most aphids when they work (see [here](#) and [here](#)). Although neem oil applications shouldn't be considered as a stand-alone solution they can provide a strong head-start when dealing with aphid infestations since they can kill a large portion of the population – if they are susceptible – without harming beneficial insects that might be predated on the aphids already. Last image in this post taken from [this paper](#).

For root aphids the option to use beneficial nematodes also exists. These worms enter the insect bodies and feed on their internal fluids, killing them in the process. However in contrast with fungal spores nematodes do actively seek their pray, so they will hunt the aphids down within the media while



a fungal spore needs to meet the aphids randomly. Single nematode species like *Heterorhabditis bacteriophora* can attack aphids although combinations using other nematode species are usually more effective since different nematodes usually attack different species with different efficiencies (see [here](#)). Mortality rates when using nematodes are usually at most around 80% so they need to be effectively used in combination with other methods to provide effective control.



**Figure 3.** Intrinsic rate of population increase ( $r_m$ ) of *Aphis gossypii* on cotton treated with aqueous extracts of neem (*Azadirachta indica*) seed powder. Temperature of  $25\pm 1^\circ\text{C}$ , relative humidity of  $70\pm 10\%$  and photophase of 12 hours.

As you can see there are several options for aphid control in your crops. Although using synthetic insecticides like imidacloprid might be the most effective alternative there are in fact other options that can also be used successfully if the use of a neonicotinoid is not desired. Application of *Lecanicillium* species has shown to be most effective in peer reviewed studies while nematode and neem applications can help compliment this approach and provide a defense against other insects and pathogens. On the next post in this series we'll talk a bit more about additional aphid control using mechanical means that are neither chemical nor biological.

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# Making your own DIY plant rooting gel

Cloning is a very common technique used by a large variety of plant growers. When growing plants from seeds there is an important unpredictability factor in what you might get so cloning ensures that you get a clear genetic copy of the parent and therefore removes a lot of the variability inherent to the growing process when starting from seed. To perform the cloning process most growers use the aid of rooting hormones which are usually sold in the form of a gel at high prices. Today we are going to learn how to make our own DIY plant rooting gel using ingredients that can be easily bought online for a fraction of the cost.



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Rooting gels have basically four ingredients. A rooting hormone (active ingredient), a gelling agent (usually an acrylic acid polymer), a base (needed to increase the

viscosity given by the gelling agent) and a preservative (because fungi eat anything). Today we are going to talk about making a rooting gel without any preservative – which is simpler – so don't make very large quantities because it can spoil after some time (probably will last for a month or so). To make this you will need the following:

- Distilled or R0 water
- Indole-3-butyric acid (you can get it [here](#)) 0.69 USD/g
- Carbopol 940 (you can get it [here](#)) 0.09 USD/g
- Potassium hydroxide (you can get it [here](#)) 0.02 USD/g
- Two containers for mixing (one around 60% of the volume you want to make, the other around 120%)
- A scale that can weight with enough precision according to the amount you want to prepare (for 1L you will need a +/- 0.1g scale).

**Warning:** Potassium hydroxide is a very strong base. Handle with a lot of care wearing protective eye wear and nitrile or PVC gloves. Do not agitate it before opening it since KOH powder is very caustic.

Once you get these ingredients the process is quite simple. For a one liter preparation add 500 mL of water to one container (we will call this one A) and 500mL to another container (which we will call B). Add 3.0g of the Indole-3-butyric acid to the A container along with 0.6g of potassium hydroxide and mix until both are dissolved. Heat the water in container B to 120-140F (48-60°C), stop heating and add 9.0g of Carbopol 940. Mix the water in container B thoroughly, the Carbopol 940 might take a long time to get hydrated and get into solution, stir it until there are no visible clumps (this can take around 15-60 minutes).

Once this process is done wait for B to cool to ambient temperature, then mix A and B slowly (in whichever has the largest container). When you do this the viscosity of the mixture will start to increase exponentially and you will have

your rooting gel preparation. The amount of money it takes to prepare 1L is around 3 USD while the most popular rooting gel products online are charging you around 16 USD for 100mL of basically the same thing. This means that you will be saving 98% of your rooting gel costs if you make your own.

There are some other additives – including preservatives and biostimulants – that we could add to make a better product, but that's a topic for another blog post.

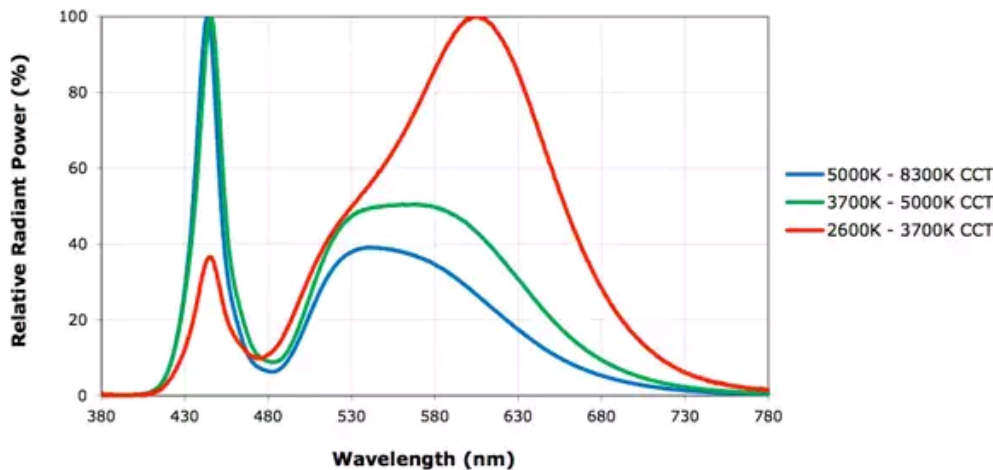
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## Building your own DIY high power LED lamp: Part One

It is no mystery that LED technology has evolved greatly during the past several years. We are now up to the point where anyone can buy LED lamps to replace HPS fixtures, with full spectrum LED configurations that have showed to be just as good – or sometimes even better – at growing crops (see [here](#) for a post about LED lights Vs HPS). However these lamps are often very expensive – most commonly around thousands of dollars to adequately replace a 1000W HPS. Within these series of posts I am going to talk about how you can build your own LED lighting to replace HPS lights for pennies on the dollar compared to commercial LED fixtures.

**WARNING:** Mains voltages (110-220V) can be extremely dangerous. Please make sure that you know what you're doing if you're going to follow these instructions. All of this information is provided "as-is" with educational purposes only. Make sure you follow all safety precautions when working on mains electricity.

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There are several ways in which you could build your own LED lamps. This usually involves building an aluminium case with fans, putting an LED driver inside and then using that driver to power rows of different light emitting diodes. A driver is basically a transformer not unlike a computer PSU that takes voltage from the mains and dials it back down to a lower voltage that you can use across a row of diodes. Most commonly commercial lamps use combinations of 3W diodes with narrow focusing elements with sometimes higher wattage elements with wider focusing elements. Building a configuration like this can be done but it is a laborious that we can avoid using some of the latest advances in LED technology.

To make a simple high power LED lamp we should absolutely forget about putting together LED elements of different colors. This involves a lot of wiring and makes the lamp fundamentally more expensive. To replace them we can use white diodes instead which although far less efficient – as they are basically blue diodes whose light is absorbed and re-emitted by a phosphor – can give us all the different colors we need in the proportions we need them. The image above shows you the spectrum of different white diodes, as you can see we don't want the 5000-8000K or 3700-5000K LEDs – which emit a lot of blue light we don't need – but we need the much “warmer” 2600-3700K diodes which produce a lot of light in the red

region of the spectra, with enough blue to provide us with close to a 1:3 ratio. Although this light spectra is still not ideal compared to what plants absorb it will easily be able to replace a 1000W HPS.

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To make things very simple and avoid using a separate driver we can use 150W LED cobs that include their own driver and are fed directly with 120/240V electricity (like the ones [here](#)). As I mentioned we want the lower temperature spectra white diodes so go for the “Warm white” and make sure the temperature description says it is at least 3200K or lower (if you’re looking at another source). The publication above contains 150W cobs that can do 2500-3200K so they can be considered ideal for this application. For every 150W cob you install you should also install a 2A AC fuse for that cob only to ensure that if anything bad happens the power will be cut almost instantly. *Since these cobs are wired directly to mains electricity you should be specially careful with having proper safety precautions (proper soldering of the wires, solders protected with isolating material (like silicon) fuses for each cob, etc).*

Of course the cobs are only half the setup. We need to place these cobs on top of an appropriate heatsink and then also ensure we have fans for it. You can buy a properly sized aluminium heat sink [here](#). Since cobs measure 16x40 we can comfortably glue two cobs to the bottom of a heat sink of profile A (146x22mm) with a length of 400mm. To glue the cobs to the heatsink you should use proper arctic silver thermal adhesive (you can find it [here](#)). For fans you can place 2 12cm Fans on top of the above. There are several fans that work with 120-240AC that you can use, for example [these fans](#) work with 120V. This setup will give us a 300W LED lamp, with 2 fans that should be able to keep the heatsink temperatures in check. All of this for a total of around 83 USD, let's call it 100 USD after adding fuses, cable and other parts you might require.

The above lamp will not replace a 1000W HPS on its own, for this you will need at least 4 cobs – meaning two of the above lamps – which should give you 600W of LED power that should be close to the PAR of a 1000W HPS light. This for the cost of only 200 USD (far less than the commercial LED replacement lights). I am in the process of making my own so I will be able to give you some additional details as soon as I get the parts and finish building my own setup. In part No.2 of this series of posts I'll show you the results of my work and what it does in terms of photon flux and PAR.

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## **What is the ideal nutrient solution temperature in**



# hydroponics?

One of the simplest variables that can make a substantial difference in crop yields in hydroponics is the temperature of the nutrient solution. Nutrient absorption by plants is mainly controlled by chemical processes within their roots and the efficacy of these processes is determined in an important part by the temperature the roots are subjected to. Since plants don't have a mechanism for active temperature regulation they just react to changes in temperature in order to best adapt to the environment that surrounds them. Today I will be talking about the optimum solution temperature in hydroponics, what influences this value and what factors we must consider when deciding what temperature to use in our hydroponic system.

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Table 2. Fresh weight, dry weight, water content and SLA of red leaf lettuce grown at four different root zone temperatures.

Root-zone temp.	Top fresh weight (g)	Root fresh weight (g)	Top dry weight (mg)	Root dry weight (mg)	Top water content (%)	Root water content (%)	SLA
10°C	3.12 ± 0.20 b	0.61 ± 0.04 b	211 ± 9 a	36 ± 2 a	93.2 ± 0.1 b	93.2 ± 0.2 b	0.51 ± 0.02 b
20°C	4.60 ± 0.28 a	0.98 ± 0.14 a	253 ± 12 a	44 ± 6 a	94.5 ± 0.1 a	95.5 ± 0.1 a	0.57 ± 0.02 a
25°C	4.51 ± 0.42 a	0.82 ± 0.07 ab	251 ± 20 a	38 ± 3 a	94.4 ± 0.1 a	95.3 ± 0.1 a	0.54 ± 0.01 ab
30°C	4.11 ± 0.35 ab	0.75 ± 0.11 ab	233 ± 19 a	35 ± 6 a	94.3 ± 0.1 a	95.4 ± 0.1 a	0.56 ± 0.02 ab

Values are mean ± SE (n = 6). Different letters in the same column indicate significant differences by Tukey's multiple comparison test (p < 0.05).

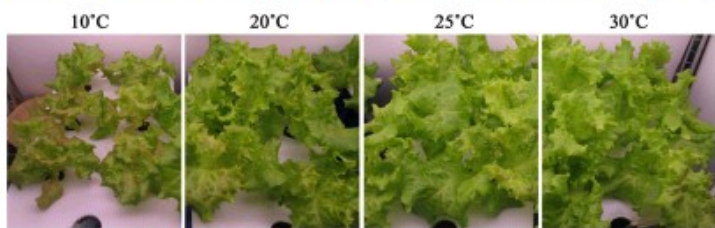


Figure 1. Effect of root-zone temperature on the morphology of red leaf lettuce.

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Solution temperature affects several important variables. Oxygen solubility changes as a function of temperature – decreasing as temperature increases – so as you increase the temperature the availability of oxygen to plant roots starts decreasing. As you increase temperature however the speed of the chemical reactions in plant roots increases, so there is an increase in respiration rates as temperature increases. The



ideal temperature is therefore always a compromise between this decrease in oxygen availability and the increase in metabolic rate that is given by higher temperatures. For almost all commercially grown plant species optimum solution temperatures will be in the 15-30°C (59-86F) range due to this reason.

However there is no rule of thumb for optimum solution temperature selection in hydroponics. It should be clear that since different plants evolved across different conditions some of them perform better at lower temperatures and some others do better at higher temperatures. We know for example that the optimum nutrient solution temperature for potatoes is in the 20-25°C range (see [here](#)) while the optimum temperature for plants like cucumbers is higher, at 28°C (see [here](#)). For some plants like onions the best solution temperature can actually be a bit higher, even in the 26-30°C range (see [here](#)). Others like lettuce and baby leaf crops actually prefer much lower temperatures, with optimum results near 20°C (see [here](#) and [here](#)).

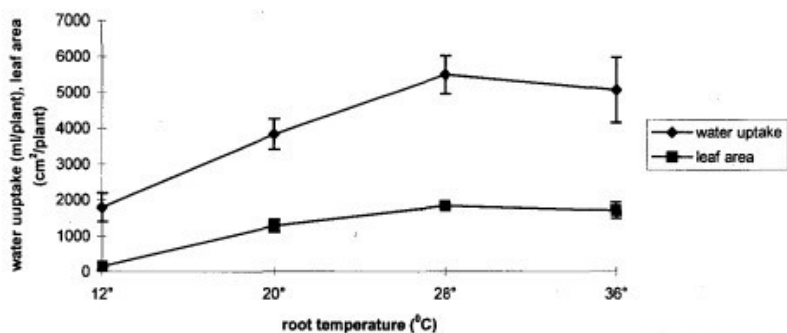


Figure 1. Water uptake and leaf area as affected by root temperature.

Cucumber

It is then clear that picking a random number between 15-30°C is not enough, a careful study of the plant species being grown has to be carried out in order to select an adequate temperature. It is also important to note that higher

temperature choices do not come without problems. We know for example that pythium and other infections are associated with increases in temperature since pathogen metabolism is also enhanced under warmer conditions (see [here](#) and [here](#)). This shows how even though the optimum temperature for tropical flowering plants is usually in the 25-30°C range, it is usually not common to see optimum results at these temperatures due to the potentially higher prevalence of diseases. This is most probably why growers usually go with a lower temperature in the 20-25°C to avoid risking diseases at a higher temperature.

If you want to try higher temperatures it is therefore better to go with sterile type hydroponic systems where microbes don't play an important role and to implement measures – such as silicate additions to the nutrient solution, UV filtration and constant oxygenation – to ensure that disease prevalence is as low as possible. Also avoid adding any source of organic carbon (like sugars) as these can play an important role in feeding incoming pathogens. Big gains can be obtained with a better solution temperature control, provided that diseases are controlled and a temperature adequate for the plant being grown is selected.

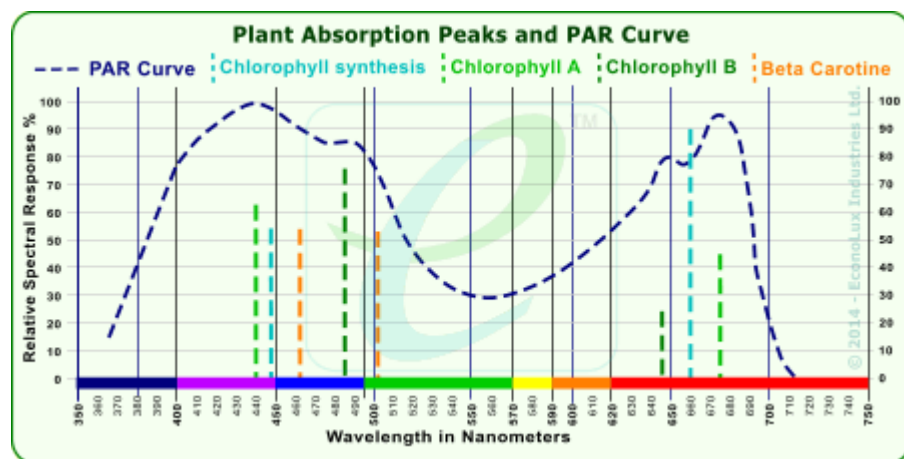
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## **Are High Pressure Sodium (HPS) Lamps better than LEDs?**

Growers who use artificial lighting usually prefer high pressure sodium (HPS) lamps to do the job. Not only do HPS lamps have a very high photon flux but compared to metal

halide (MH) lamps they have a much more prominent red spectral component and therefore a significantly larger dose of photosynthetically active radiation (PAR) per watt. However during recent years light emitting diode (LED) lamps have become much more efficient and have started to compete for the artificial lighting domain. However is there any advantage to using LED lights over HPS lamps? Are HPS lamps always going to be the winners? Today we are going to look at the science comparing HPS and LED lamps to see if there is currently a winner between the two.

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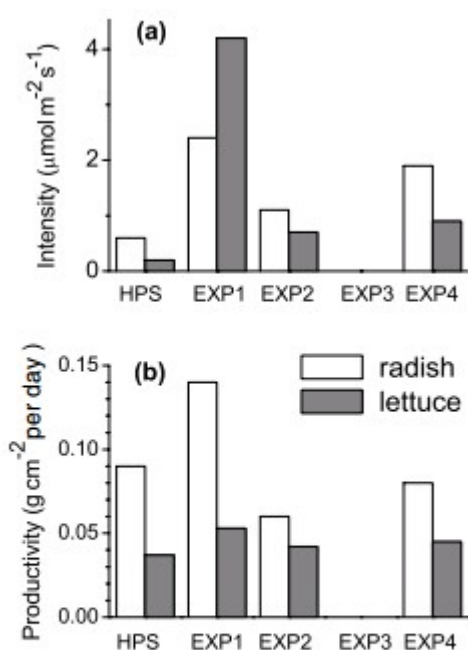


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The above graph shows you the PAR spectra. Basically this tells you which wavelengths of light are most prominently absorbed by plants. From this diagram it is clear that plants have peak absorptions around the blue and red parts of the spectra while the green section of the spectra is absorbed much less intensely and instead reflected (the reason why most plants look green). Ideally we would want lamps that have peaks in the regions of the spectra where the PAR peaks as well and we would like to have the highest peak in the red which is the region where we get the most efficient photons for the photosynthesis process.

In HPS lamps our spectra is basically fixed by the nature of

the light source while in LED lamps we can tune the light source a lot. This is one of the reasons why there is such confusion when comparing HPS and LED lamps. Since LED lamps can be tuned so much it isn't surprising that there are a large variety of cases where growers have experienced worse results from LED lamps compared with their HPS counterparts. With HPS lamps you basically buy one 1000 W lamp and you're done while with LED lamps things such as the color distribution of the diodes being used and the focusing elements they have installed can make a tremendous different.



**Figure 4.** Net photosynthesis intensity (a) and photosynthetic productivity (b) of radish (white columns) and lettuce (dark columns) grown for two weeks under illumination by HPS lamps and under LED-based illuminator in treatments EXP1 to EXP4.

Checkout [this study](#) comparing LED and HPS lights to grow lettuce and radishes. The picture above shows you the results they had with HPS lamps compared with 3 different experiments using different LED distributions. A person running setups 2 or 4 would have thought that LEDs are worse than HPS lights while someone using setup 1 would have concluded that LED lamps are simply much better. This is why some growers will

tell you that LED lamps are the greatest thing on earth while others will tell you they are never as good as HPS – they simply have used different lamps. Notice that in setup 3 a complete breakdown of the photosynthetic process happened.

In the above experiment growers used 4 LED types, 455nm, 640nm, 660nm and 735nm LEDs in a roughly 10:120:10:1 ratio. In setup 2 the 640nm LED intensity was reduced by a factor of 1.5, in the setup 3 the 735nm component was changed to nighttime only and in setup 4 the 735nm LED was changed to only two hours during nighttime. You can see how the decision to change a light source that contributed less than 2% of the total light flux to nighttime had a very important effect. This is because the 735nm wavelength has a circadian rhythm effect that can substantially change how the plant responds. Just turning on 2% of the LEDs at the wrong time completely turned around the results.

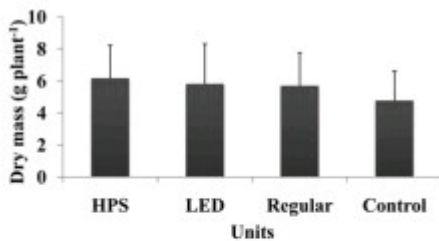


Fig. 5. Final average plant dry biomass for Boston lettuce (*Lactuca sativa* var. *capitata*) grown hydroponically under different treatments in a controlled environment. HPS = high-pressure sodium; LED = light-emitting diode; Regular = regular greenhouse HPS levels; Control = no supplemental artificial lighting. Harvest of 10 plants from each treatment averaged over two replications with sd bars.

With the above it is not surprising that we find contradictory evidence in the scientific literature. Articles [like this](#) paper on cucumbers find that HPS provides better growing efficiency compared to LED lamps in line with other articles like [this one](#) on lettuce. However we should bear in mind that

the LED lamps used are always different and the fact that a LED array provides worse results compared to HPS does not mean that this is true for all LED lamps overall. Since LED lamps can be tuned so much it is almost certain that for a given plant specie you will always find an LED combination that gives you at least the same results as an HPS lamp.

Nonetheless the power savings from LED lamps also need to be considered. In experiments where comparable photon fluxes are used LED lamps tend to provide savings of at least 30-40% in terms of power consumed from the lamps only while these savings can reach even higher values when considering the additional cooling needs of HPS lamps (that are often much lower for LED lamps).

Per the above LED lamps are definitely worth considering as a replacement for HPS lamps. However you need to properly build your LED lamps such that the photon flux and spectral composition does provide you with results that can surpass those of regular HPS. Building a lamp that is underpowered or that has an inappropriate spectral composition can indeed cause you to get results inferior to those of HPS lamps. This is most probably the reason why so many growers are so reluctant to move to this type of solutions when using either only artificial or supplemental artificial lighting.

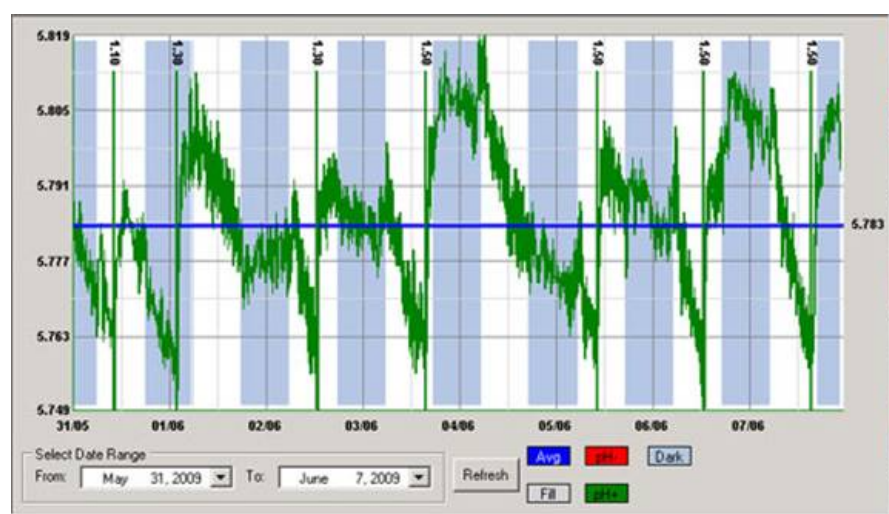
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## **Five dos and don'ts for automated pH control in hydroponics**

The pH is one of the most important variables to control in hydroponic culture as it plays a key role in the availability

of different ions and their absorption dynamics. Although most growers control pH manually it is often desirable to implement automatic pH control so that you can ensure that your solution always stays within an optimum range. This is especially true in recirculating systems where correcting the pH of the solution after it goes through the plants' roots is necessary. Today I want to share with you five dos and don'ts when implementing automated pH control in hydroponic culture.

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**Do test your pH meter frequently with a buffer solution.** In hydroponics pH meters can lose calibration rather quickly as a consequence of being immersed in a nutrient solution that is at a lower ionic concentration than what's ideal for most glass electrodes. This means that testing your pH meter with a buffer solution often – every week is ideal – is necessary in order to ensure that you are getting accurate readings. If the reading is not accurate you can then recalibrate the meter.

**Do recondition your pH meter every month.** In line with the above and in other to increase the life of a pH meter and each calibration it's necessary to immerse the pH electrodes in a pH 4 or 7 buffer solution every month – for at least 2-3 hours – to ensure that the ionic content of the electrode is

restored and the glass membrane's responsiveness remains accurate. If you do this your electrode will be happier and you will need to calibrate less frequently. If an electrode is covered in biofilm the putting it in a hot bleach solution for half an hour before the buffer immersion is also necessary.

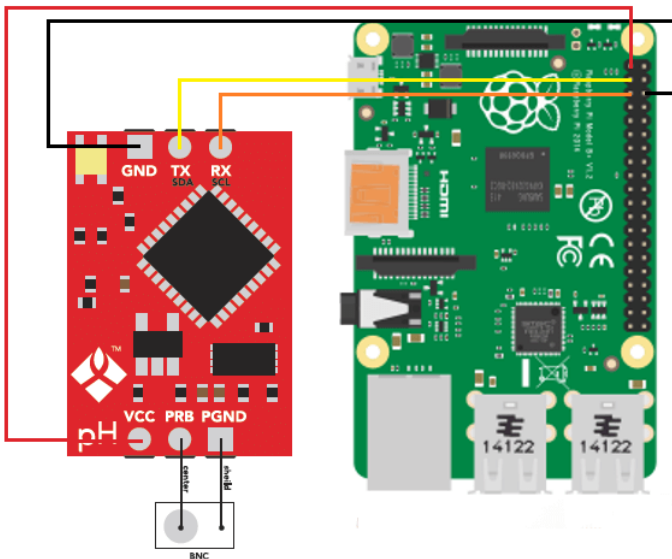
**Do use electrodes designed for constant immersion.** Regular pH electrodes – including those sold with some automated pH controllers – are not meant to be immersed the whole time and therefore get damaged and lose calibration much more quickly when used in this manner. To get best results use pH electrodes that are fabricated with long term immersion in mind. I wrote a blog post about [these electrodes](#) and why they are different than traditional pH electrodes.

**Do place your electrode as far as possible from your pH changing inputs.** When using a pH controller you should place the pH probe as far away as possible from the place where your pH up/down solutions will enter the hydroponic system. This is so that your pH electrode can get a slow change in pH as the pH up/down is mixed with the entire reservoir. Placing the probe close to the inputs will cause very erratic changes in the pH that do not really reflect the effect of the addition across the entire reservoir.

**Do have addition limits in your controllers.** Allowing a pH controller to add as much substance as needed to correct the pH can be a very bad thing to do. This is because several things can go wrong – pH probe losing calibration, controller getting damaged, electrical noise etc- that can cause unnecessary levels of addition that can kill an entire crop. Always have controllers where maximum additions per unit of time can be specified so that the possibility of this happening is minimized.

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**Don't rely on a single pH probe.** Although single probe controllers are the most common they can also be the most dangerous. A pH probe can get damaged, it can lose calibration or it can give erratic readings due to other reasons (for example electrical interference from other things in the reservoir). Therefore it's always best to use two-probe controllers where readings are always verified across the two probes to ensure that the reading the controller is getting is accurate. If you have a commercial enterprise then this is a must, you wouldn't want to lose an entire crop due to a bad pH probe adding a ton of acid/base to your solution.

**Don't aim for a specific pH value.** A pH controller should not aim for a specific value of pH but to maintain pH within an adequate range. Usually the best way for a controller to act is to have a range with high/low thresholds where the controller will act to take the pH to the middle of the range when these thresholds are exceeded. For example a controller can be told to maintain pH in the 5.6-6.4 region and then it will act whenever the pH reaches 5.6 or 6.4 to take it back to 6 when any one of these two thresholds is breached. However if the pH is at 6.4 and the controller drops it to 5.8 it will not try to then bring the pH up (because it's above the lower

threshold).

**Don't place your pH probes near pumps or other electrical equipment in reservoirs.** A pH probe takes an electrical measurement and is therefore prone to electrical interference. Having a pH probe close to other electrical equipment – especially those that draw significant current – can cause those wires to induce currents in the pH probe wires and generate all sorts of issues with pH readings. Always place pH probes away from pumps and ensure the pH probe and pump wires are never tangled together.

**Don't use very concentrated acid/base input solutions.** A pH controller will be doing very fine control over a small pH range so it won't need a very large amount of acid/base to do this job. Using very concentrated acid/base can cause the pH controller to completely overshoot its targets and cause it to either cause the system to get into an undesirable state – for example a very low pH if the controller can only add acid – or enter a loop where acid additions are followed by base additions in an endless cycle. Usually you want your acid/base mixtures to be concentrated enough to shift the pH over their addition volume but not much more than that. Strong acids/bases in the 10-20% concentration range are usually more than enough for this job.

**Don't ignore your controller's data.** A pH controller will do its job – control pH within a range – but it will not tell you whether your system is doing ok or not from a plant-health perspective. How often your pH controller has to add acid/base and how much acid/base it's using to perform its job are important pieces of information that you need to take into account in order to ensure that your system is working properly. Remember that pH controlling substances often also contribute nutrients – like phosphorous or potassium – so it's important to keep all these additions in check.

Of course pH control is no simple task and different pH

controllers will have different advantages and disadvantages. However doing what you can to ensure proper maintenance – cleaning, conditioning electrodes, having proper placement, etc – can go a long way in ensuring that your setup behaves as ideally as possible. If you can then I would advice you build your own controllers using things like arduinos, raspberry pi computers and robust immersion pH probes so that you can have an optimum setup that can deliver all the advantages of pH control with as few disadvantages as possible. I'll write about building your own pH controller in a future post.

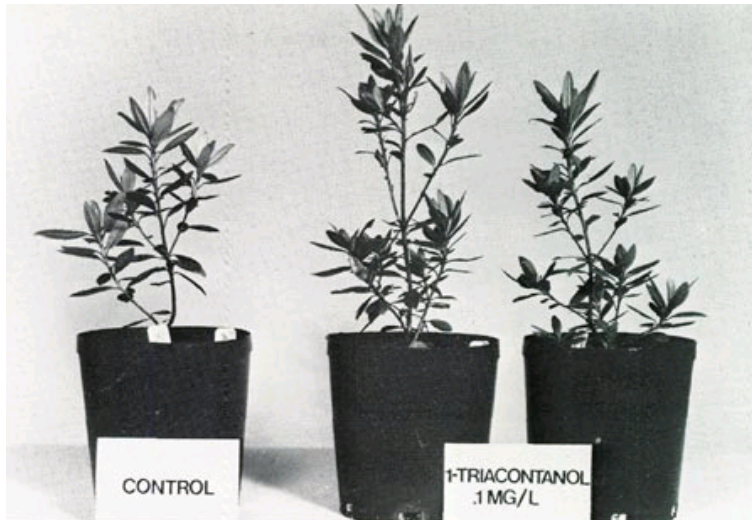
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## Using triacontanol to increase yields in hydroponics

Usually additives used in hydroponics need to be added in rather large quantities to obtain palpable results. Molecules like salicylic acid – which we have [discussed before](#) – need to be used in concentrations in the order of  $10^{-4}$  to  $10^{-2}$  M to obtain a significant effect. This means that you need to use quantities in the order of 20-150ppm of most additives in order to see a significant result. However there is a molecule called 1-triacontanol that can generate very significant results with only a fraction of that concentration. Today we will talk about this substance, what it does, how to use it and why it's such a desirable tool in your hydroponic additive arsenal. Many of the things I will talk about in this article are derived from [this 2011 review](#) on triacontanol (make sure you read that for a deeper insight into why this molecule

works).

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Triacontanol is a very long fatty alcohol. Each molecule has 30 carbon atoms linked in a linear structure which makes this molecule extremely hydrophobic and hence very hard to dissolve in something like water. Using triacontanol therefore involves dissolving this molecule in something other than water – for example Tween 20, chloroform, methanol – before adding water in order to prepare an emulsion for use in either root applications or foliar feeding. Most research using triacontanol has used foliar feeding as this is the easiest way to control the application of the molecule and also how it seems to have the largest effect.

The effects of this molecule are not short of miraculous. Triacontanol is usually applied in concentrations on the order of  $10^{-7}$  to  $10^{-9}$  M, which means it is used from around 0.01 to 1 ppm. This means that we use about 1000 times less triacontanol than other additives in order to obtain a meaningful result. The table below shows some of the effects that triacontanol has showed in peer reviewed studies, with plant height, weight and yields increasing across a variety of different species, from tomatoes to japanese mint. Papers on other plants besides

those on the chart have also been published, for example triacontanol has showed to significantly increase yields in lettuce crops ([here](#)). Some studies have also found that the effect of triacontanol can also be enhanced through the use of magnesium or in conjunction with other hormones ([here](#)).

Table 1 Positive response of various plant species to foliar application of triacontanol.

Name of plant	Botanical name	Family name	Growth attributes	Yield attributes	Biochemical attributes	Quality attributes	Reference citation
Opium poppy	<i>Papaver somniferum</i> L.	Papaveraceae	Plant height, dry weight and number of branches	Number of capsules, seed yield per plant, and crude opium yield per plant	Chl <i>a</i> , Chl <i>b</i> , and total content	Morphine content and morphine yield per plant	Khan et al. (2007)
Tomato	<i>Solanum lycopersicum</i> L.	Solanaceae	Height per plant, number of leaves and plant fresh and dry weights	Number of fruits per plant, weight per fruit and fruit yield per plant	Total chl and carotenoids content, leaf-N, -P, and -K contents	Fruit ascorbic acid and lycopene contents	Khan et al. (2009)
Hyacinth bean	<i>Lablab purpureus</i> L.	Fabaceae	Plant fresh and dry weights, leaf-area per plant, number and dry weights of nodules	Number of pods per plant, number of seeds per pod, 100-seed weight and seed-yield per plant	Photosynthetic rate ( $P_N$ ), stomatal conductance (gs) and transpiration rate, total chl and carotenoid content, NR and CA activities, leaf-N, -P, -K, and -Ca content, nodule-N and leghemoglobin contents	Seed-protein content, total carbohydrate content, and tyrosinase activity	Naeem and Khan (2005), Naeem et al. (2009)
Artemisia	<i>Artemisia annua</i> L.	Asteraceae	Shoot and root lengths, plant fresh and dry weights	Artemisinin yield	$P_N$ , gs and transpiration rate, total chl and carotenoid content, NR and CA activities, leaf-N, -P, and -K content	Essential oil content, artemisinin content	Aftab et al. (2010)
Coriander	<i>Coriandrum sativum</i> L.	Umbelliferae	Shoot and root lengths, plant fresh and dry weights		Total chl and carotenoids content, NR and CA activities, leaf-N, -P, and -K content	Essential oil content	Idrees et al. (2010)
Coffee senna	<i>Senna occidentalis</i> L.	Fabaceae	Plant fresh and dry weights	Number of pods per plant, number of seeds per pod, 100-seed weight and seed yield per plant	$P_N$ , gs and transpiration rate, total chl and carotenoid content, NR and CA activities, leaf-N, -P, -K, and -Ca content	Total anthraquinone and sennoside contents, and seed-protein content	Naeem et al. (2010)
Sweet basil	<i>Ocimum basilicum</i> L.	Labiatae	Shoot and root lengths, number of spikes per plant, total leaf area, plant fresh and dry weights	Essential oil yield	Chl <i>a</i> , Chl <i>b</i> , total Chl, and carotenoid contents, activities of NR and CA, leaf-N, -P, and -K contents	Leaf-protein and carbohydrate contents, essential oil content, linalool, methyl eugenol, and eugenol contents	Hashmi et al. (2011)
Japanese mint	<i>Mentha arvensis</i> L.	Lamiaceae	Plant height, leaf-area, leaf-yield, and plant fresh and dry weights	Herbage yield, essential oil yield	Total chl and carotenoid contents, activities of NR and CA, leaf-N, -P, and -K contents, total phenol	Essential oil content, menthol, L-menthone, isomenthone, and menthyl acetate contents	Naeem et al. (2011)

Abbreviation: Chl, Chlorophyll; NR, Nitrate reductase; CA, Carbonic anhydrase.

With such an impressive array of effects and such a low expected toxicity – due to its very low solubility – it's definitely one of the best additives to use to get production gains in hydroponic crops. This also makes it one of the most commonly used substances in commercially available grow enhancers. Nonetheless since it's used in such a small quantity it's very easy for someone to buy a small amount of triacontanol and use it for years before running out. You can buy small amounts of triacontanol as a powder (there are several reputable sellers on ebay) and you can then prepare

your own concentrated triacontanol solution in Tween 20 – not water – that will last you for ages. A liter of 2000ppm solution of triacontanol will last you for 1000-2000 liters of foliar spray. You cannot get more economical than that.

The optimum application rate and frequency for triacontanol varies across different species but if you want to take an initial guess use a foliar application of a 0.5 ppm solution every week. There is usually a sweet spot for concentration – after that you start to see a decrease in results compared to the highest point – so you want to start below a 1 ppm application rate. For some crops repeated applications might be unnecessary – with just one or two applications giving most of the effect through the entire crop cycle – while for others you do want to apply every week. How you initially dissolve the triacontanol to make your concentrated solution is also important with Tween 20 being the most ecologically friendly – although not the easiest – option.